Indian J. Fish., 72 (4): 47-54, 2025
doi:10.21077/ijf.2025.72.4.169233-06
Available online at: epubs.icar.org.in/index.php/IJF

Performance of tire track eel (*Mastacembelus favus* Hora, 1924) fry reared at different stocking densities in composite tanks

Doan Xuan Diep[1], **Lai Phuoc Son**[2] and **Huynh Kim Huong**[2*]
[1]Faculty of Applied Science and Technology, Nguyen Tat Thanh University, Ho Chi Minh City, Vietnam
[2]School of Agriculture and Aquaculture, Tra Vinh University, Vinh Long Province, Vietnam

Abstract

This study aimed to evaluate the rearing performance of *Mastacembelus favus* fry under three different stocking densities: 50, 75, and 100 individuals per cubic meter (ind. m^{-3}). The experiment was conducted over a period of 180 days, from September 2022 to March 2023, using 0.5 m^3 composite tanks in a completely randomised design with three replicates per treatment. The yolk sac-exhausted fry (1.08 g and 6.54 cm) were reared under the trial stocking densities and fed commercial pellet feed throughout the rearing period. A stocking density of 100 ind m^{-3} had a significantly adverse effect on most of the measured performance parameters, including mean weight, mean length, daily weight gain, daily length gain, survival rate, feed conversion ratio, and productivity ($p<0.05$). While most performance indicators did not differ significantly between the 50 and 75 ind m^{-3} treatments ($p>0.05$), productivity at 75 ind m^{-3} was significantly higher than at 50 ind m^{-3} ($p<0.05$). These findings suggest that a stocking density of 75 ind m^{-3} was optimal for rearing *M. favus* fry under the study conditions.

*Correspondence e-mail:
hkhuong77@tvu.edu.vn

Keywords:
Environmental sustainability, Growth, Productivity, Survival rate, Vietnam

Received : 19.07.2025
Accepted : 20.12.2025

Introduction

Aquaculture plays a vital role in supporting rural livelihoods and ensuring global food and nutrition security (Ogello and Munguti, 2016). It is also the world's fastest-growing food production sector, expanding at an average rate of 6% per year over the past decade (FAO, 2018). However, the quick growth of the sector has led to environmental issues, especially with cage culture and pond-intensive systems in natural water bodies, where it is still difficult to strike a balance between sustainability and productivity (Waite *et al*., 2014; Munguti *et al*., 2021). Climate change is also putting extra strain on the industry, resulting in more frequent extreme weather events, restricted land and feed resources, and water scarcity (IPCC, 2007; Adhikari *et al*., 2018). Tank-based aquaculture is widely recognised as a sustainable approach, enabling year-round, intensive production under controlled conditions that enhance resource efficiency and waste management (Chávez-Crooker and Obreque-Contreras, 2010; Ansari *et al*., 2017; Estim *et al*., 2019). Additionally, tanks lower the dangers of genetic and water contamination (McLean, 2021).

Mastacembelus favus Hora, 1924, commonly known as the tire track eel, is a freshwater species native to South-east Asia and often naturally encountered in the tropical rivers (Froese and Pauly, 2013; Jamsari *et al*., 2014). It is farmed across counties in these areas, typically in Thailand, Laos, Cambodia, Peninsular Malaysia, and Vietnam (Roberts, 1986; Jamaluddin *et al*., 2019). *M. favus* eels are highly regarded in aquaculture due to their desirable taste, high nutritional quality, and significant market potential (Gupta and Banerjee, 2016; Jamaluddin *et al*., 2019). Additionally, they are generally resistant to diseases and compatible with simple, low-input farming systems (Jamaluddin *et al*., 2019; Nguyen *et al*., 2024b). In developing countries, *M. favus* is widely consumed either fresh or dried and is occasionally sold in the aquarium trade (Islam and Rani, 2017). In Vietnam's Mekong Delta, tire track eels are particularly noteworthy due to their high market price. They are cultured in earthen ponds and sometimes in ponds lined with plastic. It is mainly fed on formulated diets, trash fish, or homemade feeds (Danh, 2018; Nguyen *et al*., 2024a, b; Loan and Phuong, 2025). *M. favus* eels exhibit a relatively slow growth rate. In their natural habitat, one-year-old individuals weigh 150–250 g and measure 18–25 cm in length, while two-year-old individuals generally weigh 450–500 g and reach 35–40 cm (Rainboth, 1996; Trieu, 2010). This species can attain a maximum weight of 500 g and a maximum length of 90 cm (Pethiyagoda, 1991). A survey by Nguyen *et al*. (2024b) on small-scale *M. favus* culture in the Vietnamese Mekong Delta reported that the fry-to-fingerling phase requires approximately 2.5 months to reach an average size of 3 g, with a survival rate of 55.7%. Meanwhile, the fingerling-to-commercial harvest phase lasts 11.8–14 months, producing harvest sizes of 318.2–421.4 g and survival rates of 40–80%.

In aquaculture, optimal stocking densities enhance yield, financial returns, and environmental sustainability. Fish performance may be adversely affected by excessively high (Salas-Leiton *et al*., 2010; Yadata *et al*., 2020; Chen *et al*., 2021) or low (Shubha and Reddi, 2011; Aragon-Flores *et al*., 2014) stocking densities. Non-optimal densities may induce physiological and behavioural stress, affecting growth, reproduction, welfare, and survival (Mollah *et al*., 2015; Santurtun *et al*., 2018). Furthermore, overcrowding not only leads to chronic stress and changes in body composition (Hoseini *et al*., 2020) but also raises production costs and negatively impacts the environment (Mollah *et al*., 2015). As a result, choosing the right stocking density is crucial to maximising performance in various aquaculture systems (Rahman *et al*., 2012; Yadata *et al*., 2020).

This study evaluated the rearing performance of *M. favus* fry in composite tanks under different stocking densities to identify the optimal density that supports a productive culture system while minimising potential environmental impacts.

Materials and methods

Yolk sac-exhausted tire track eel (*M. favus*) fry, with an initial mean size of 1.08 g and 6.54 cm, were obtained from a locally produced hatchery stock. The fry were acclimated to the experimental conditions for one week prior to the start of the trial. Freshwater sourced from the river was used in the experiment. It was treated with 2 mg l^{-1} potassium permanganate ($KMnO_4$) and continuously aerated for 2 to 3 days. The treated water was then pumped to the rearing tanks across layers of cotton to remove suspended matter. Composite tanks with a capacity of 0.5 m^3 were used for rearing the fish. The rearing tanks maintained the water depth at 0.6 m and and were continuously aerated throughout the experiment. A Gold King Aqua commercial pellet feed from Goldking Company Ltd., Vietnam, which contained 46% crude protein, 12% crude fat, 5% crude fiber, and 11% moisture, was fed to the fish during the rearing period.

Experimental parameters and data collection

The study lasted for 180 days, from September 2022 to March 2023, in the wet laboratory of the Department of Freshwater Aquaculture, College of Aquaculture and Fisheries, Tra Vinh University, Vietnam. It aimed to evaluate the effects of different stocking densities (50, 75, and 100 ind m^{-3}) on the rearing performance of tire track eel (*M. favus*) fry in 0.5 m^3 round composite tanks. The experiment was conducted in nine rearing tanks, following a completely randomised design with three replications for each tested density. Fish were fed twice daily, at 6:00 and 14:00 hrs, at a rate of 4% of their wet body weight. To maintain water quality, accumulated waste and faeces were siphoned from the tank bottoms daily, and any water removed during this process was promptly replaced. The water in the rearing tanks was circulated through a biological filtration system at a rate equivalent to 100–120% per day. No water changes were made in the rearing tanks during the first week of the experiment. From the second week onward, 10–20% of the water was replaced every 3 to 5 days, depending on the water quality in the tanks.

Water quality parameters in the rearing tanks were monitored throughout the experiment. Temperature (°C) and pH were measured twice daily at 7:00 and 14:00 hrs using a pH meter (Hana, manufactured in Romania). Total ammonia nitrogen (TAN, mg l^{-1}) and nitrite (NO_2^-, mg l^{-1}) were tested every three days at 7:00 hrs using a test kit (Sera, Germany).

The growth performance was monitored monthly, with 30 fish from each tank sampled randomly. Individual weight was measured using a digital scale with 0.01 g precision, while total length was recorded to the nearest millimeter using a graduated ruler. At the end of the experiment, survival rate, feed conversion ratio, productivity, coefficient of variation, and weight-grouped proportion were recorded and calculated. The equations used are as follows:

$$\text{Daily weight gain (DWG, g day}^{-1}) = \frac{(\text{Final weight} - \text{Initial weight})}{\text{No. of rearing days}}$$

$$\text{Daily length gain (DLG, cm day}^{-1}) = \frac{(\text{Final length} - \text{Initial length})}{\text{No. of rearing days}}$$

$$\text{Specific growth rate in weight (SGRw, \% day}^{-1}) = \frac{[\ln(\text{final weight}) - \ln(\text{initial weight})]}{\text{No. of rearing days}} \times 100$$

$$\text{Specific growth rate in length (SGR\_L, \%day}^{-1}) = \frac{[\ln(\text{final length}) - \ln(\text{initial length})]}{\text{No. of rearing days}} \times 100$$

$$\text{Survival rate (SR, \%)} = \frac{\text{Number of fish survived}}{\text{No. of fish stocked}} \times 100$$

$$\text{Feed conversion ratio (FCR)} = \frac{\text{Total dry feed given (g)}}{\text{Total wet weight gain of fish (g)}}$$

$$\text{Productivity: Productivity (g m}^{-3}) = \frac{\text{Biomass}}{\text{Rearing volume}}$$

$$\text{Coefficient of variation in weight (CVw, \%)} = \frac{\text{Standard deviation}}{\text{Mean body weight)}} \times 100$$

$$\text{Weight Grouped Proportion (GPw, \%)} = \frac{\text{Number of fish in weight group}}{\text{Total no. of fish)}} \times 100$$

Data analysis

SPSS software, version 20.0 for Windows, was used to statistically evaluate all the variables that were measured in this study. At a significance threshold of $p<0.05$, a one-way analysis of variance (ANOVA) and Duncan's multiple range test were used to identify significant differences between mean values. Prior to analysis, percentage data were arcsine-transformed, and the homogeneity of variances was evaluated using Levene's test.

Results and discussion

Water quality parameters

Throughout the experimental period, water quality parameters showed minimal variation. Temperature ranged from 26.46 to 27.72°C, pH from 8.01 to 8.02, TAN from 0.02 and 0.03 mg l^{-1}, and the NO_2^- from 0.01 and 0.03 mg l^{-1} (Table 1). Water quality parameters recorded across all stocking densities fall within the optimal ranges for the healthy development of tire track eels (Boyd and Tucker, 1998; Jayakumar and Abdul Nazar, 2013; Banmali *et al*., 2020).

Rearing performance

Increasing stocking density is a common technical strategy to enhance fish productivity and optimise the use of land and water resources. However, excessively high stocking densities can have detrimental effects on aquaculture performance, including reduced growth and survival rates, increased susceptibility to disease, and deterioration of water quality (Jia *et al*., 2022). The effects of stocking density differ across cultured species and are influenced by factors such as developmental stage and environmental or managerial conditions (Chen *et al.,* 2021; Karnatak *et al.,* 2021). Therefore, additional research is required to determine the ideal stocking densities in aquaculture systems (Nhan *et al.,* 2022). In this study, stocking densities of 50 to 100 ind m^{-3} were evaluated to determine their influence on the rearing performance of *M. favus* fry in the tank system.

According to monthly monitoring data, fish raised at a density of 100 ind m^{-3} had the lowest mean weight (MW) and mean length (ML) values from day 30 onward. These values were significantly lower than those of fish raised at 50 and 75 ind m^{-3} ($p<0.05$), but there were no significant differences between the 50 and 75 ind m^{-3} densities ($p>0.05$). Furthermore, at a stocking density of 100 ind m^{-3}, the DWG and DLG parameters showed their lowest values, which were significantly lower than those at 50 ind m^{-3} at the end of the rearing period ($p<0.05$) (Table 2 and 3).

By the end of the trial, CVw and GPw were not significantly affected by stocking density (Table 4, Fig. 1), but other parameters, including SR, FCR, and productivity, were significantly lower at 100 ind m^{-3} compared to 50 and 75 ind m^{-3} ($p<0.05$). The highest productivity was recorded at 75 ind m^{-3}, significantly higher than at both 50 and 100 ind m^{-3} ($p<0.05$). There were no significant variations in SR or FCR between the 50 and 75 ind m^{-3} densities ($p>0.05$) (Table 4) .

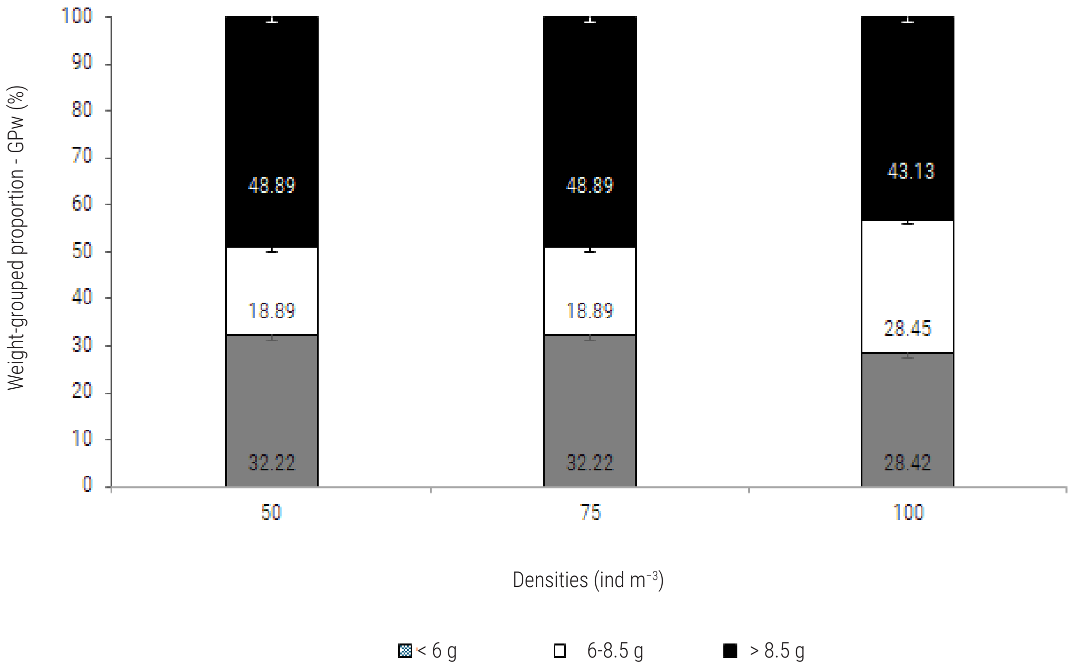

Fig. 1. Weight-grouped proportion of *M. favus* fry after the 180 days rearing period under three stocking densities. Values are presented as mean±SD. The same colour segments on different bars with same letters (a) show no significant difference ($p>0.05$)

Table 1. Water quality parameters during the 180-day rearing period under three stocking densities. Values are presented as Mean±SD.

Parameters	Test time	Densities (ind m^{-3})		
		100	75	50
Temperature (°C)	7:00	26.60 ± 0.72	26.46 ± 0.80	26.48 ± 0.78
	14:00	27.72 ± 0.72	27.63 ± 0.76	27.63 ± 0.80
pH	7:00	8.01 ± 0.23	8.02 ± 0.19	8.01 ± 0.20
TAN (mg $l^{-)}$		0.02±0.01	0.02±0.01	0.03±0.01
NO_2^- (mg l^{-1})		0.01 ± 0.00	0.02 ± 0.0.00	0.03 ± 0.0.01

Table 2. Mean weight (MW), weight gain (WG), daily weight gain (DWG), and specific growth rate in weight (SGRw) of *M. favus* fry during the 180 day rearing period under three stocking densities. Values are presented as Mean±SD. Values with different letters (a, b) in the same are significantly different ($p<0.05$).

Densities (ind m^{-3})	Day	50	75	100
MW (g ind^{-1})	30	$2.32±1.03^b$	$2.32±1.02^b$	$1.74±0.69^a$
	60	$5.23±2.06^b$	$5.22±2.12^b$	$4.02±2.16^a$
	90	$6.34±2.23^b$	$7.12±3.36^b$	$5.28±2.53^a$
	120	$8.00±3.74^b$	$8.4±4.49^b$	$5.68±3.29^a$
	150	$8.26±4.33^b$	$8.19±3.39^b$	$6.44±2.35^a$
	180	$9.75±6.28^b$	$8.89±4.67^b$	$7.85±3.28^a$
WG (g ind^{-1})	180	$8.67±3.34^a$	$7.81±3.96^a$	$6.77±4.49^a$
DWG (g day^{-1})	180	$0.05±0.03^b$	$0.04±0.03^{ab}$	$0.03±0.019^a$
SGRw (% day^{-1})	180	$1.18±0.33^a$	$1.15±0.35^a$	$1.13±0.03^a$

Table 3. Mean length (ML), length gain (LG), daily length gain (DLG), and specific growth rate in length (SGRL) of *M. favus* fry during the 180-day rearing period under three stocking densities. Values are presented as Mean±SD. Values with different letters (a, b,) in the same row are significantly different ($p<0.05$).

Densities (ind m^{-3})	Days	50	75	100
ML (cm ind^{-1})	30	$8.43±1.25^b$	$8.36±1.32^b$	$7.56±1.08^a$
	60	$11.37±1.65^b$	$10.91±1.76^b$	$9.90±2.14^a$
	90	$12.7±1.84^b$	$12.55±2.56^b$	$11.66±2.13^a$
	120	$13.9± 2.33^b$	$13.44±3.02^b$	$12.0±2.42^a$
	150	$13.41±2.89^b$	$13.76±2.58^b$	$10.80±2.17^a$
	180	$15.09±2.88^b$	$15.02±2.84^b$	$13.93±2.18^a$
LG (cm ind^{-1})	180	$8.24±2.85^a$	$8.21±2.74^a$	$7.52±2.47^a$
DLG (cm day^{-1})	180	$0.28±0.09^b$	$0.28±0.09^{ab}$	$0.25± 0.08^a$
SGR_l (% day^{-1})	180	$0.45±0.1^a$	$0.44±0.12^a$	$0.43±0.12^a$

Table 4. Survival rate (SR), feed conversion ratio (FCR), productivity, and coefficient of variation in weight of *M. favus* fry after the 180 – days rearing period under three stocking densities. Values are presented as Mean±SD. Values with different letters (a, b) in the same row are significantly different ($p<0.05$).

Densities (ind m^{-3})	50	75	100
SR (%)	$67.33±4.18^b$	$69.33±7.23^b$	$44.67±1.52^a$
FCR	$2.33±0.33^a$	$2.00±0.00^a$	$3.67±0.58^b$
Productivity (g m^{-3})	$762.75±40.59^a$	$930.49±97.92^b$	$701.27±23.98^a$
CVw (%)	$27±11^a$	$31±18^a$	$29±7^a$

The highest density (100 ind m^{-3}) resulted in a significant reduction in nearly all growth parameters from day 30 onward and negatively affected SR, FCR, and overall productivity by the end of the trial. Conversely, the lowest density (50 ind m^{-3}) led to a marked decline in productivity after 180 days of rearing. Many fish species have evidenced a decrease in growth performance when they were farmed and surpassed species-specific density thresholds. For example, after 360 days, *Piaractus mesopotamicus* raised at a density of 650 g m^{-3} showed higher biomass and weight gain than fish kept at higher densities (Montenegro *et al*., 2022). In hybrid snakeheads (*Channa* sp.), excessive stocking densities have been shown to impede growth and decrease yield *via* reducing SGR (Wu *et al*., 2017). Additionally, when housed at higher densities in PVC tanks, juvenile *Scophthalmus maximus* displayed slower growth and greater body weight variance (Irwin *et al*., 1999).

There are numerous reasons why fish at high stocking densities have limited growth. Excessive stocking density has been shown in earlier research to be one of the causes of chronic stress, which can result in negative physiological and biochemical changes. It damages cells, inhibits the immune system, creates oxidative stress, and upsets intracellular homeostasis, as was observed in *Penaeus (Litopenaeus) vannamei* (Liu *et al*., 2017), fingerlings of *Oreochromis niloticus* (Liu *et al*., 2018), and fry of *Ompok bimaculatus* (Majhi *et al*., 2023) in biofloc systems; juvenile *Acipenser sinensis* in recirculating systems (Long *et al*., 2019); and *Aulonocara* sp. in plastic tanks (Mahalakshmi *et al*., 2024). Additionally, crowding stress raises the energy demands needed to cope with physiological responses, thereby reducing the energy available for growth (Yang *et al*., 2020; Jia *et al*., 2022). It also intensifies competition for feed and space (Jia *et al*., 2022), while increased territorial behaviour at high stocking densities can lead to injury and even mortality (Hecht and Pienaar, 1993).

The adverse effects of crowding were probably the reason for the notable decrease in survival rate of *M. favus* fry at the highest stocking density (100 ind m^{-3}). This trend was also observed by previous authors in other fish (Chiu *et al.,* 2020; Ni *et al*., 2020). Even in more spacious farming systems like integrated rice–fish farming, elevated stocking densities have been shown to decrease the survival of *M. salmoides* (Jia *et al*., 2022).

FCR is an important indicator used to measure how much feed is needed to produce a specific quantity of fish. A lower FCR reflects better feed efficiency (Fry *et al*., 2018; Rodde, 2020). In our study, FCR increased significantly at 100 ind m^{-3}, indicating reduced feed utilisation efficiency under this condition. This finding aligns with previous studies reporting increased FCR at higher stocking densities (Saputra *et al*., 2018; Hieu *et al*., 2022; Jewel *et al*., 2023). It is known that crowding stress leads to additional energy expenditure for maintaining homeostasis (Leland *et al*., 2013; Pederzoli and Mola, 2016). Under stress, fish exhibited higher metabolic rates to support respiration, osmoregulation, movement, and tissue repair, so less energy is spent on building the body, resulting in reduced feed conversion efficiency (Arifin *et al*., 2014).

Growth performance, survival rate, and FCR are critical parameters influencing the commercial success of aquaculture, as they are directly related to overall production (Caballero-Zamora *et al*., 2015; Thitamadee *et al*., 2016; Gjedrem and Rye, 2018). In the present study, all of these parameters declined significantly at a stocking density of 100 ind m^{-3}, which negatively influenced productivity. While key rearing performance indicators, including growth performance, SR, FCR, CVW, and GPW, did not differ significantly between the 50 and 75 ind m^{-3} stocking densities, a significantly lower productivity was observed at 50 ind m^{-3}. This reduction is likely attributable to the smaller initial stocking quantity, which limited the total biomass yield of the fish. It indicates a suboptimal utilisation of tank capacity at the low stocking density.

In the present study, the FCR of 2 recorded at a stocking density of 75 ind m^{-3} for *M. favus* fry falls within the range of 1.91–4.07 reported by Loan and Phuong (2025) for *M. favus* fingerlings reared on different diets, as well as the range of 2–5 noted by Nguyen et al. (2024b). Remarkably, the survival rate of 69.33% during the present study, was greater than the value of 55.7% reported by Nguyen *et al*. (2024b) (for *M. favus* fry raised in soil or soil-lined ponds. Additionally, the SGR of 1.15% day^{-1} recorded in the present study was higher than the range (0.86–1.06% day^{-1}) recorded for *M. favus* fry raised with similar tank conditions by Banmali *et al*. (2020), but at higher stocking densities (100–400 ind m^{-3}) over a 60-day period.

On the other hand, social hierarchies are a major factor contributing to variations in growth rate and body size within fish populations (Metcalfe *et al*., 1989; Johnsson, 1997; Metcalfe, 2006). Dominant, larger individuals often limit the feeding opportunities and growth of subordinate, smaller fish (Cutts *et al*., 2005; Martins, 2005). Social hierarchies are often given special attention in aquaculture because they closely relate to the profitability of production *via* influence on aggressive behaviour, stress levels, overall health, feed efficiency, growth, mortality, productivity and even the market value of farmed fish. Parameters such as grouped proportion (GP) and coefficient of variation (CV) are commonly used to assess social hierarchies in fish populations (Martins, 2005). In the present study, no significant differences in GP_W and CV_W were observed among the different stocking densities. Notably, a CV_W of 31% was recorded at a stocking density of 75 ind m^{-3}, which falls within the typical range of 20–35% reported for various fish species (Gjedrem, 1997). These results indicated that increasing the stocking density to 75 ind m^{-3} did not considerably affect the social hierarchy of the experimental fish stock.

In conclusion, high stocking density (100 ind m^{-3}) negatively impacted growth performance, survival, FCR, and productivity. Conversely, low stocking density (50 ind m^{-3}) led to a significant reduction in the productivity of experimental fish. The findings suggest that a stocking density of 75 ind m^{-3} is optimal for rearing *M. favus* fry in our study conditions. Further research in hydroponics or biofloc tank systems is recommended to enhance the rearing performance of this fish.

Acknowledgements

We acknowledge the support of time and facilities from Tra Vinh University (TVU) and Nguyen Tat Thanh University for this study.

References

Adhikari, S., Baral, H. and Nitschke, C. 2018. Adaptation to climate change in Panchase Mountain ecological regions of Nepal. *Environments,* 5(3): 42. https://doi.org/10.3390/environments5030042.

Ansari, F. A., Singh, P., Guldhe, A. and Bux, F. 2017. Microalgal cultivation using aquaculture wastewater: Integrated biomass generation and nutrient remediation. *Algal Res.,* 21: 169–177. https://doi.org/10.1016/j.algal.2016.11.015.

Aragon-Flores, E. A., Valdez-Hernandez, E. F., Martinez-Cardenas, L., Castañeda-Chavez, M. R., Gonzales-Diaz, A. A., Soria-Barreto, M., Ruiz-Velazco, J. M. J. and Peña-Messina, E. 2014. Effect of stocking density on growth, survival and condition of the Mexican cichlid *Cichlasoma beani*. *J. World Aquac. Soc.,* 45(4): 447–453. https://doi.org/10.1111/jwas.12136.

Arifin, M. Y., Supriyono, E. and Widanarni. 2014. Total hemocyte, glucose and survival rate of mantis shrimp (*Harpiosquilla raphidea*), posttransportation with two different systems. *J. Kelaut. Nas.,* 9(2): 111–119. http://dx.doi.org/10.15578/jkn.v9i2.6207 (In Indonesian).

Banmali, P., Tam, B. M. and Liem, P. T. 2020. Effect of different stocking densities on growth performance and survival of tire track eel (*Mastacembelus favus*) in a recirculating aquaculture system. *Int. J. Sci. Res.,* 10(9): 1135–1141. https://doi.org/10.21275 /SR21920100501.

Boyd, C. E. and Tucker, C. S. 1998. *Pond aquaculture water quality management*. Dordrecht: Kluwer Academic Publishers, The Netherlands. https://doi.org/10.1007/978-1-4615-5407-3.

Caballero-Zamora, A., Montaldo, H. H., Campos-Montes, G. R., Cienfuegos-Rivas, E. G., Martínez-Ortega, A. and Castillo-Juárez, H. 2015. Genetic parameters for body weight and survival in the Pacific white shrimp *Penaeus (Litopenaeus) vannamei* affected by a white spot syndrome virus (WSSV) natural outbreak. *Aquaculture,* 447: 102–107. https://doi.org/10.1016/j.aquaculture.2014.08.028.

Chávez-Crooker, P. and Obreque-Contreras, J. 2010. Bioremediation of aquaculture wastes. *Curr. Opin. Biotechnol.,* 21(3): 313–317. https://doi.org/10.1016/j.copbio.2010.04.001.

Chen, L., Yang, Y. O., Rizwan, M., Khan, I. M., Yue, D. D., Yao, F. and Huang, S. J. 2021. Compensatory growth in gibel carp (*Carassius auratus gibelio*) after the stress of stocking density. *Aquac., Res.* 52(4): 1697–1704. https://doi.org/10.1111/are.15022.

Chiu, P. S., Chu, Y. T., Huang, C. H., Ho, S.W., Huang, J. W. and Yeh, S. L. 2020. Effects of stocking density on growth performance, survival and size heterogeneity of juvenile longfin batfish *Platax teira*. *Aquac. Res.,* 51: 5269–5272. https://doi.org/10.1111/are.14858.

Cutts, C. J., Metcalfe, N. B. and Taylor, A. C. 2005. Aggression and growth depression in juvenile Atlantic salmon: The consequences of individual variation in standard metabolic rate. *J. Fish Biol.,* 52(5): 1026-1037. https://doi.org/10.1111/j.1095-8649.1998.tb00601.x.

Danh, T. V. 2018. Trial of nursing tire-track eel (*Mastacembelus favus*) in canvas-coated ponds at different stocking densities with water management by recycling aquaculture system. *Research Project Report*, Department of Agriculture and Rural Development of Vinh Long Province, Vietnam, 41 p.

Estim, A., Saufie, S. and Mustafa, S. 2019. Water quality remediation using aquaponics sub-systems as biological and mechanical filters in aquaculture. *J. Water Process. Eng.,* 30: 100566. https://doi.org/10.1016/j.jwpe.2018.02.001.

FAO 2018. *The state of world fisheries and aquaculture 2018 – Meeting the sustainable development goals.* Food and Agriculture Organization of the United Nations, Rome, Italy.

Froese, R. and Pauly, D. 2013. *FishBase. Worldwide web electronic publication.* http://www.fishbase.org (Accessed 04 October 2013).

Fry, J. P., Mailloux, N. A., Love, D. C., Milli, M. C. and Cao, L. 2018. Feed conversion efficiency in aquaculture: Do we measure it correctly? *Environ. Res. Lett.,* 13(2): 024017. https://doi.org/10.1088/1748-9326/aaa273.

Gjedrem, T. 1997. Selective breeding to improve aquaculture production. *World Aquac., 28: 33-45.*

Gjedrem, T. and Rye, M. 2018. Selection response in fish and shellfish: A review. *Rev. Aquac.,* 10: 168–179. https://doi.org/10.1111/raq.12154.

Gupta, S. and Banerjee, S. 2016. Food, feeding habit and reproductive biology of tire-track spiny eel (*Mastacembelus armatus*): A review. *J. Aquac. Res. Dev.,* 7: 429. https://doi.org/10.4172/2155-9546.1000429.

Hecht, T. and Pienaar, A. G. 1993. A review of cannibalism and its implications in fish larviculture. *J. World Aquac. Soc.,* 24(2): 246–261. https://doi.org/10.1111/j.1749-7345.1993.tb00014.x.

Hieu, T. K., Van, V. T. T., Thien, P. C. and Diep, D. X. 2022. Effects of different stocking densities on growth and survival rate of Dau Nhim snakehead (*Channa* sp.) fingerlings. *AACL Bioflux,* 15(3): 1124–1132.

Hoseini, S. M., Mirghaed, A. T., Ghelichpour, M., Pagheh, E., Iri, Y. and Kor, A. 2020. Effects of dietary tryptophan supplementation and stocking density on growth performance and stress responses in rainbow trout (*Oncorhynchus mykiss*). *Aquaculture,* 519: 734908. https://doi.org/10.1016/j.aquaculture.2019.734908.

IPCC 2007. Summary for policymakers. In: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor, M. and Miller, H. L. (Eds.), *Climate change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, UK.

Irwin, S., O'Halloran, J. and FitzGerald, R. 1999. Stocking density, growth and growth variation in juvenile turbot (*Scophthalmus maximus* Rafinesque). *Aquaculture,* 178: 78–88. https://doi.org/10.1016/S0044-8486(99)00122-2.

Islam, M. S. and Rani, T. 2017. Larval rearing and the observation of the development features in striped spiny eel, *Mastacembelus pancalus*, in captive condition. *J. Entomol. Zool. Stud.,* 5(6): 2488–2493.

Jamaluddin, J. A. F., So, N., Bui, M. T., Amiruddin, A., Chaiwut, G., Page, L. M., Khaironizam, M. Z. and Siti Azizah, M. N. 2019. Genetic variation, demographic history and phylogeography of tire track eel, *Mastacembelus favus* (Synbranchiformes: Mastacembelidae) in Southeast Asia. *Hydrobiologia,* 838: 163–182. https://doi.org/10.1007/s10228-021-00807-4.

Jamsari, A. F. J., Nam, S., Tam, B. M. and Siti-Azizah, M. N. 2014. Isolation and characterisation of microsatellite loci in the tire track eel, *Mastacembelus favus*, and cross-species amplification. *Conserv. Genet. Resour.,* 6(2) 477–479. https://doi.org/10.1007/s12686-013-0132-1.

Jayakumar, R. and Abdul Nazar, A. K. 2013. *Marine fish hatchery: Concept, design, and construction.* ICAR-Central Marine Fisheries Research Institute, Kochi.

Jewel, M. A. S., Ara, J., Haque, M. A., Hossain, M. A., Noor, N. M. and Das, S. K. 2023. Effect of stocking density on the growth, body composition, and blood parameters of cage-reared Gangetic mystus catfish (*Mystus cavasius*). *Aquac. Rep.,* 28: 101428. https://doi.org/10.1016/j.aqrep.2022.101428.

Jia, R., Wang, L., Hou, Y., Feng, W., Li, B. and Zhu, J. 2022. Effects of stocking density on the growth performance, physiological parameters, redox status and lipid metabolism of *Micropterus salmoides* in integrated rice–fish farming systems. *Antioxidants,* 11(7): 1215. https://doi.org/10.3390/antiox11071215.

Johnsson, J. I. 1997. Individual recognition affects aggression and dominance relations in rainbow trout (*Oncorhynchus mykiss*). *Ethology,* 103(4): 267–282. https://doi.org/10.1111/j.1439-0310.1997.tb00017.x..

Karnatak, G., Das, B. K., Mishal, P., Tayung, T., Kumari, S., Sarkar, U. K. and Ali, Y. 2021. Impact of stocking density on growth, feed utilization and survival of cage-reared minor carp, *Labeo bata* (Hamilton, 1822) in Maithon Reservoir, India. *Aquaculture,* 532: 736078. https://doi.org/10.1016/j.aquaculture.2020.736078

Leland, J. C., Butcher, P. A., Broadhurst, M. K., Paterson, B. D. and Mayer, D. G. 2013. Damage and physiological stress to juvenile eastern rock lobster (*Sagmariasus verreauxi*) discarded after trapping and hand collection. *Fish. Res.,* 137: 63–70. https://doi.org/10.1016/j.fishres.2012.09.001

Liu, B., Liu, Y. and Sun, G. 2017. Effects of stocking density on growth performance and welfare-related physiological parameters of Atlantic salmon (*Salmo salar* L.) in a recirculating aquaculture system. *Aquac. Res.,* 48: 2133–2144. https://doi.org/10.1111/are.13050.

Liu, G., Ye, Z., Liu, D., Zhao, J., Sivaramasamy, E., Deng, Y. and Zhu, S. 2018. Influence of stocking density on growth, digestive enzyme activities, immune responses, and antioxidant status of *Oreochromis niloticus* fingerlings in biofloc systems. *Fish Shellfish Immunol.,* 81: 416–422. https://doi.org/10.1016/j.fsi.2018.07.047.

Loan, P. P. and Phuong, N. T. 2025. Effects of dietary protein and lipid levels on growth, feed utilization, and body composition of tire track eel (*Mastacembelus favus*) fingerlings. *J. Aquac. Bamidgeh,* 77(1): 48–58. https://doi.org/10.46989/001c.128999.

Long, L., Zhang, H., Ni, Q., Liu, H., Wu, F. and Wang, X. 2019. Effects of stocking density on growth, stress, and immune responses of juvenile Chinese sturgeon (*Acipenser sinensis*) in a recirculating aquaculture system. *Comp. Biochem. Physiol. C: Toxicol. Pharmacol.,* 219: 25–34. https://doi.org/10.1016/j.cbpc.2019.02.002.

Mahalakshmi, S., Antony, C., Ravaneswaran, K., Uma, A. and Sunder Lingam, R. S. 2024. Influence of biofloc and stocking density on physiological responses and disease resistance in peacock cichlid (*Aulonocara* sp.). *Aquaculture,* 592: 741168. https://doi.org/10.1016/j.aquaculture.2024.741168.

Majhi, S. S., Singh, S. K., Biswas, P., Debbarma, R., Parhi, J., Khatei, A., Mangang, Y. A., Waikhom, G. and Patel, A. B. 2023. Stocking density affects immune and stress-related gene expression of butter catfish (*Ompok bimaculatus*) fry in biofloc landscapes. *Fish Shellfish Immunol.,* 5: 100112. https://doi.org/10.1016/j.fsirep.2023.100112.

Martins, C. I. M. 2005. *Individual variation in growth of African catfish (Clarias gariepinus): A search for explanatory factors*. Ph. D thesis. Wageningen University, The Netherlands.

McLean, E. 2021. Fish tank color: An overview. *Aquaculture,* 530: 735750. https://doi.org/10.1016/j.aquaculture.2020.735750.

Metcalfe, N. B. 2006. Intraspecific variation in competitive ability and food intake in salmonids: Consequences for energy budgets and growth rates. *J. Fish Biol.,* 28(5): 525–531. https://doi.org/10.1111/j.1095-8649.1986.tb05190.x.

Metcalfe, N. B., Huntingford, F. A., Graham, W. D. and Thorpe, J. E. 1989. Early social status and the development of life-history strategies in Atlantic salmon. *Proc. R. Soc. Lond. B,* 236(1282): 7–19. https://doi.org/10.1098/rspb.1989.0009.

Mollah, M. F. A., Moniruzzaman, M. and Rahman, M. A. 2015. Effects of stocking densities on growth and survival of Thai sharpunti (*Barbonymus gonionotus*) in earthen ponds. *J. Bangladesh Agric. Univ.,* 9(2): 327–338. https://doi.org/10.3329/jbau.v9i2.11048.

Montenegro, L. F., Cunzolo, S., Preussler, C. A., Hennig, H. H., Descalzo, A. M. and Perez, C. D. 2022. Effects of stocking density on productive performance, economic profit and muscle chemical composition of pacu (*Piaractus mesopotamicus* H) cultured in floating cages. *Aquac. Res.,* 53(5): 3379–3391. https://doi.org/10.1111/are.15845.

Munguti, J., Obiero, K., Orina, P., Mirera, D., Kyule, D., Mwaluma, J., Opiyo, M., Musa, S., Ochiewo, J., Njiru, J., Ogello, E. and Hagiwara, A. 2021. *State of aquaculture report 2021: Towards nutrition-sensitive fish food production systems.* Techplus Media House.

Nguyen, N. H. Y., Tran, N. K., Nguyen, H. T. B. and Trinh, L. T. 2024a. Optimal dietary lipid level for the growth of tire track eel (*Mastacembelus favus*) fingerling. *SSRN*https://doi.org/10.2139/ssrn.4855725.

Nguyen, N. H. Y., Nguyen, H. T. T., Nguyen, H. T. B., Phan, V. T. T., Tran, T. D., Ho, M. V. M. and Trinh, L. T. 2024b. Investigation of small-scale farming status of tire track eel (*Mastacembelus favus*) in the Mekong Delta, Vietnam. *J. Agric. Dev.,* 23(3) :11–22.

Nhan, D. T., Tu, N. P. C. and Tu, N. V. 2022. Comparison of growth performance, survival rate and economic efficiency of Asian seabass (*Lates calcarifer*) intensively cultured in earthen ponds with high densities. *Aquaculture,* 554: 738151. https://doi.org/10.1016/j.aquaculture.2022.738151.

Ni, J., Wang, Y., Xu, G., Nie, Z., Sun, Y., Li, Q. and Xu, P. 2020. Effects of stocking density on growth, physiological indices and expression of GH and IGF-I genes of largemouth bass (*Micropterus salmoides*) in in-pond raceway culture systems. *J. Dalian Ocean Univ.*, 35(6): 805–813..

Ogello, E. O. and Munguti, J. M. 2016. Aquaculture: Promising solution for food insecurity, poverty and malnutrition in Kenya. *Afr. J. Food Agric. Nutr. Dev.*, 16: 11331–11350. https://doi.org/10.18697/ajfand.76.15900.

Pederzoli, A.A. and Mola, L. 2016. The early stress responses in fish larvae. *Acta Histochem.*, 118: 443–449. https://doi.org/10.1016/j.acthis.2016.03.001.

Pethiyagoda, R. 1991. *Freshwater fishes of Sri Lanka*. The Wildlife Heritage Trust of Sri Lanka, Colombo. 362 p.

Rahman, M. A., Zaher, M., Azimuddin, K. M., Yeasmine, S., Khan, M. M. and Arshad, A. 2012. Stocking density effects on growth and production of the threatened silurid catfish, *Mystus cavasius* (Hamilton) fingerlings in nursery ponds. *Aquac. Res.*, 44(7): 1132–1139. https://doi.org/10.1111/j.1365-2109.2012.03148.x.

Rainboth, W. J. 1996. *Fishes of the Cambodian Mekong. FAO Species identification field guide for fishery purposes*. Food and Agriculture Organisation of the United Nations, 265 p.

Roberts, T. R. 1986. Systematic review of the Mastacembelidae or spiny eels of Burma and Thailand, with descriptions of two new species of *Macrognathus*. *Japan. J. Ichthyol.*, 33: 95–109. https://doi.org/10.11369/jji1950.33.95.

Rodde, C., Chatain, B., Vandeputte, M., Trinh, T.Q., Benzie, J. A. H. and Verdal, H. 2020. Can individual feed conversion ratio at commercial size be predicted from juvenile performance in individually reared Nile tilapia (*Oreochromis niloticus*)? *Aquac. Rep.*, 16: 100349. https://doi.org/10.1016/j.aqrep.2020.100349.

Salas-Leitón, E., Anguis, V., Martín-Antonio, B., Crespo, D., Planas, J. V., Infante, C., Cañavate, J. P. and Manchado, M. 2010. Effects of stocking density and feed ration on growth and gene expression in the Senegalese sole (*Solea senegalensis*): Potential effects on the immune response. *Fish Shellfish Immunol.*, 28(2): 296–302. https://doi.org/10.1016/j.fsi.2009.11.006.

Santurtun, E., Broom, D. M. and Phillips, C. J. C. 2018. A review of factors affecting the welfare of Atlantic salmon (*Salmo salar*). *Anim. Welfare*, 27: 193–204. https://doi.org/10.7120/09627286.27.3.193.

Saputra, A. T. B., Samsudin, R. and Rahmadya, N. D. 2018. Growth performance and survival of snakehead (*Channa striata*) juveniles at different stocking densities reared in a recirculation system. *J. Akuakultur Indon.*, 17(2): 104–112. https://doi.org/10.19027/jai.17.2.104-112.

Shubha, M. and Reddi, S. R. 2011. Effect of stocking density on growth, maturity, fecundity, reproductive behaviour and fry production in the mouth brooding cichlid *Oreochromis mossambicus* (Peters). *Afr. J. Biotechnol.*, 10: 9922–9930. https://doi.org/10.5897/AJB11.697.

Thitamadee, S., Prachumwat, A., Srisala, J., Jaroenlak, P., Salachan, P. V., Sritunyalucksana, K., Flegel, T. W. and Itsathitphaisarn, O. 2016. Review of current disease threats for cultivated penaeid shrimp in Asia. *Aquaculture*, 452: 69–87. https://doi.org/10.1016/j.aquaculture.2015.10.028.

Trieu, N. V. 2010. Study on biological characteristics of *Mastacembelus armatus*. *Can Tho Univ. J. Sci*., 15(b): 70-80.

Waite, I. R., Kennen, J. G., May, J. T., Brown, L. R., Cuffney, T. F., Jones, K. A. and Orlando, J. L. 2014. Stream macroinvertebrate response models for bioassessment metrics: Addressing the issue of spatial scale. *PLoS ONE*, 9(3): e90944. https://doi.org/10.1371/journal.pone.0090944.

Wu, X., Ma, H., Gao, S., Chen, Y. and Lin, S. 2017. Physiological responses of hybrid snakehead (*Channa maculata × C. argus*) to different stocking densities. *Fish. Sci.*, 36(5): 557–562. https://www.aquaticjournal.com/article/doi/10.16378/j.cnki.1003-1111.2017.05.003.

Yadata, G. W., Ji, K., Liang, H., Ren, M., Ge, X. and Yang, Q. 2020. Effects of dietary protein levels with various stocking density on growth performance, whole body composition, plasma parameters, nitrogen emission and gene expression related to TOR signaling of juvenile blunt snout bream (*Megalobrama amblycephala*). *Aquaculture*, 519: 734730. https://doi.org/10.1016/j.aquaculture.2019.734730.

Yang, Q., Guo, L., Liu, B. S., Guo, H. Y., Zhu, K. C., Zhang, N., Jiang, S. G. and Zhang, D. C. 2020. Effects of stocking density on the growth performance, serum biochemistry, muscle composition and HSP70 gene expression of juvenile golden pompano *Trachinotus ovatus* (Linnaeus, 1758). *Aquaculture*, 518: 34841. https://doi.org/10.1016/j.aquaculture.2019.734841